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Strength Improvement of Weak Subgrade Soil Using Cement and Lime

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Abstract-The study investigate suitability of subgrade soil in Baure Local Government Area of Katsina State Nigeria for road construction. The strength properties of the subgrade were improved using lime and cement. Several analysis including particle size distribution, specific gravity, Atterberg limits, compaction characteristics, unconfined compressive strength and California bearing ratio tests were performed on natural and lime/cement treated soil samples in accordance with BS 1377 (1990) and BS 1924 (1990) respectively. Soil specimens were prepared by mixing the soil with lime and cement in steps of 0, 3, 6, and 9% by weight of dry soil in several percentage combinations. The Atterberg limits of weak subgrade soils improved having a minimum plasticity index value of 5.70 % at 3%Lime/6%Cement contents. Maximum dry density (MDD) values obtained showed a significant improvement having a peak value of 1.66 kN/m^3 at 9%Lime/9%Cement contents. Similarly, a minimum value of 18.50 % was observed for optimum moisture content at 9%Lime/9%Cement contents which is a desirable reduction from a value of 25.00 % for natural soil. The unconfined compressive test value increased from 167.30 kN/m^2 for natural soil to 446.77 kN/m^2 at 9%Lime/9%Cement contents 28 days curing period. Likewise, soaked California bearing ratio values increased from 2.90 % for the natural soil to 83.90 % at 9%Lime/9%Cement contents. Generally, there were improvements in the engineering properties of weak subgrade soil when treated with lime and cement. However, peak UCS value of 446.77 kN/m^2 fails to meet the recommended UCS value of 1710 KN/m^2 specified by TRRL (1977) as a criterion for adequate stabilization using Ordinary Portland Cement.

Keywords: Weak subgrade soil, Lime, Cement, Atterberg limits, Maximum dry density, Optimum moisture content, Unconfined compressive strength, California bearing ratio

1 INTRODUCTION

Soil stabilization significantly changes the characteristics of a soil to produce long-term strength and stability. Subgrade layer is the lowest layer in the pavement structure underlying the base course, depending upon the type of pavement. Generally, subgrade consists of various locally available soil materials that sometimes might be soft and/or wet that cannot have enough strength/stiffness to support pavement loading (Sadeeq *et al.*, 2014a; b) A sound knowledge of performance of the subgrade soil under prevailing in-situ condition is necessary prior to the construction of the pavement. The better the strength/stiffness quality of the materials the better would be the long-term performance of the pavement (Salahudeen *et al.*, 2014). Hence, design of pavement should be focused on the efficient, most economical and effective use of existing subgrade materials to optimize their performance. In case of soft and/or wet (weak) subgrade soils, proper treatment is needed in order to make them workable and meet the required engineering standards for pavement and other engineering construction works. Understanding the engineering properties of subgrade is crucial to obtain strength and economic performance of the pavement (Amadi, 2015).

In road works, there is a great need for soil material flexible pavements construction. When a section of the road is to be filled with soil, the material is either obtained from other cut section along the road or from borrow pit where the suitable material is present if the material from the road does not meet the required standards. A major cost that would be incurred in "borrowing" the soil material is that involved in hauling the material from the borrow pit to the construction site. A cost effective solution, in terms of finance, resources and time, could however be achieved by simply improving the engineering properties of subgrade material that was earlier rejected (Anderson, 2012).

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In some regions (especially southern region) or even urban areas of Nigeria, unviability of the aggregate or the shortage of the suitable fill materials makes replacement of weak subgrade soil uneconomical (Salahudeen *et al.*, 2013). In such conditions, the strength/stiffness properties of the existing weak subgrade soil can be improved by the use of proper compaction technique as well as by using some chemical stabilizers. Portland cement, lime and fly ash are the most common types of chemical stabilizers used by most of states to stabilize the weak subgrades; thus creating a proper working platform and/or sub-base layer for pavement construction.

In geotechnical engineering, soil improvement could either be by modification or stabilization, or both (Salahudeen and Akiije 2014). Stabilization is the process of blending and mixing materials with a soil to improve the soil's strength and durability (Butalia *et al.*, 2003). Shriram (2015) describes soil stabilization as the treatment of natural soil to improve its engineering properties. In general, soil stabilization is the process of creating or improving certain desired properties in a soil material so as to render it stable and useful for specific purpose at minimum cost. Amadi (2015), states that the improvements in engineering properties caused by stabilization can include the following: increase in soil strength (shearing resistance), stiffness (resistance to formation) and durability (wearing resistance), reduction in swelling potential or dispersivity (tendency to deflocculates) of wet clay soils and other desirable characteristics, such as dust proofing and water proofing unsealed roads.

According to National Association of Lime (Texas), "lime", either alone or in combination with other materials, can be used to treat a range of soil types. The mineralogical properties of the soils will determine their degree of reactivity with lime and the ultimate strength

that the stabilized layers will develop. In general, fine-grained clay soils (with a minimum of 25 percent passing the No. 200 sieve (74 mm) and a Plasticity Index greater than 10) are considered to be good for stabilization. Abu-Farsakh, *et al.* (2004) determined consistency limits, compaction properties, and uniaxial-strength of cement/lime stabilized soil. They concluded that by increasing the optimum moisture content (%) of the soil mixtures, the maximum dry density decreased.
The scarcity of good construction material plus inherent economy in utilizing locally available materials in the construction of modern highway systems and other engineering projects in Baure local government area of Katsina State in particular, has placed emphasis on the stabilization of weak soil materials to meet the present as well as the anticipated engineering specifications of subgrade materials. The study is aimed at improving the engineering properties of weak soil of Baure L.G.A Katsina State, using lime and cement as admixtures
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2 Materials and Methods

2.1 Materials

Soil: The disturbed soil sample used for this study was collected in February 2017 at Tsamiyar-kwance (Latitude $12^0 47'15''$N and longitude $8^0 27'43''$E), Baure Local Government Area of Katsina State along Gangarawa, which is 1km from Baure town. The soil samples were sealed in plastic bags and put in sacks to avoid loss of moisture during transportation. The soil sample was then air–dried, pulverized and then sieved through several standard sieves for different types of tests with the largest sieve being BS No. 4 sieve (4.76 mm aperture).
Cement: The cement used in this study was an Ordinary Portland Cement (OPC) obtained from an open market in Samaru market, Zaria, Kaduna State. See Table 1 for the oxide composition of Ordinary Portland Cement used for this study. The chemical compositions of the OPC and lime were determined at the Centre for Energy Research and Training (CERT), ABU, Zaria using the method of Energy Dispersive X-Ray Fluorescence. The major compounds in cement that are responsible for important reactions in soil stabilization using cement are shown in Table 2.

Table 1. Chemical composition of Ordinary Portland Cement and Lime

Oxide Compounds	Composition values (%)	
	OPC	Lime
CaO	65	78
SiO_2	21	18
Al_2O_3	6.15	2.5
Fe_2O_3	3.92	1.1
MgO	1.23	0.6
SO_3	1.02	0.3
K_2O	0.2	0.1
Na_2O	0.11	0.1
TiO_2	0.28	-
MnO	0.01	-
BaO	0.02	-
V_2O_5	0.02	-
Loss on Ignition	0.81	-

Table 2. Major compounds of cement

Name of Compound	Formula	Abbreviation
Tricalcium silicate	3 $CaO.SiO_2$	C_3S
Dicalcium silicate	2 CaO.SiO2	C_2S
Tricalcium aluminate	3 $CaO.Al_2O_3$	C_3A
Tetracalcium alumina ferrite	4 $CaO.Al_2O_3.Fe_2O_3$	C_4AF

Lime: The lime used for this study was obtained from Sokoto Cement Factory, Sokoto the capital of Sokoto State of Nigeria. The lime was passed through British Standard No. 200 sieve and kept to be mixed with the soil in the appropriate percentages. Table 1 shows the approximate oxide composition limits of typical Lime.

2.2 Methods

General and index properties tests: Laboratory tests were performed to determine the index properties of the natural soil and lime/cement treated weak subgrade soil in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. A total of 16 soil/admixture samples were prepared for the study. All tests carried out were done at 0, 3, 6 and 9 % lime/cement treatment by dry weight of the natural soil as shown in Table 3.

Table 3. Samples of soil/Cement/Lime batching

S1	S9
0%Lime + 0%Cement	**3% Lime + 6%Cement**
S2	**S10**
0% Lime + 3%Cement	3% Lime + 9%Cement
S3	**S11**
0% Lime + 6%Cement	6% Lime + 3%Cement
S4	**S12**
0% Lime + 9%Cement	6% Lime + 6%Cement
S5	S13
3% Lime + 0%Cement	6% Lime + 9%Cement
S6	**S14**
6% Lime + 0%Cement	9% Lime + 3%Cement
S7	**S15**
9% Lime + 0%Cement	9% Lime + 6%Cement
S8	**S16**
3% Lime + 3%Cement	9% Lime + 9%Cement

Compaction: The compaction tests were performed on the natural soil and the lime treated soils using the British Standard light (BSL) energy.
Strength tests: Strength tests performed were used to determine the unconfined compressive strength (UCS) and California bearing ratio (CBR) values of the soil samples. The UCS test specimens were compacted at BSL energy and cured for 7, 14 and 28 days before testing. The CBR tests were carried out in accordance with Nigerian General Specifications (1997) which specifies that specimens be cured in the open air for six days and then soaked for 24 hours before testing.

3 Results and Discussion

3.1 Properties of the Natural Subgrade Soil

Preliminary tests performed show that the natural soil is an A-4 (2) soil according to the AASHTO classification system (AASHTO, 1986) and low plasticity clay (CL), using the Unified Soil Classification System, USCS (ASTM, 1992). The natural soil has low moisture content of 14.70 %, specific gravity of 2.62, liquid limit of 25.00%, plastic limit of 18.30%, plasticity index of 6.70 % with 67.30% of the soil particles passing through the BS. No 200 sieve. Table 4 and Figure 1 respectively show the summarized properties of the natural soil and its particle size distribution curve.

Table 4. Properties of the Natural Lateritic Soil

Properties	Description
Natural moisture content (%)	14.70
Percentage passing BS No. 200 (%)	67.30
Liquid limit (%)	25
Plastic limit (%)	18.3
Plasticity index (%)	6.7
Linear shrinkage (%)	10.4
Free Swelling (%)	40
Group Index	2
AASHTO classification	A – 4
USCS	CL
Specific gravity	2.62
Maximum dry density (Mg/m³)	1.4
Optimum moisture content (%)	25
California bearing ratio (%)	2.90
Unconfined compressive strength (kN/m²)	167
Colour	Black

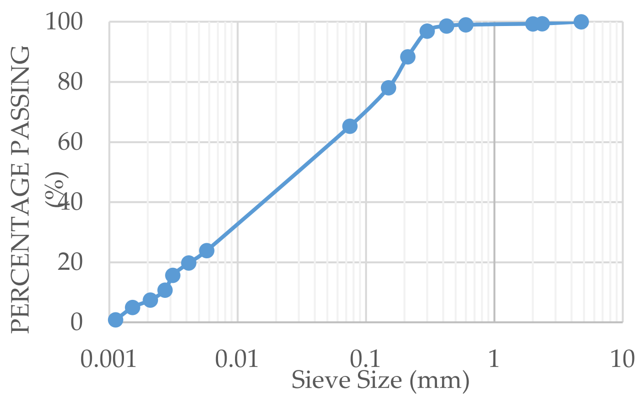

Fig. 1: Particle size distribution curve for the natural soil

3.2 Particle Size Distribution of Subgrade Soil Mixed with Lime and Cement

The particle size distribution curves for soil treated with lime/cement content are shown in Figure 2. It can be observed that with increase in admixture (lime/cement content), the particle size distribution curves shifted to the right thereby showing decrease in the percentage of fines at the steps 0, 3, 6 and 9% of lime content. A little change is noticed in the coarser sizes; this is an indication that with increase in lime/cement content, modification reaction between lime, cement and clay minerals increased which facilitated the formation of relatively coarser particles (Salahudeen, 2014).

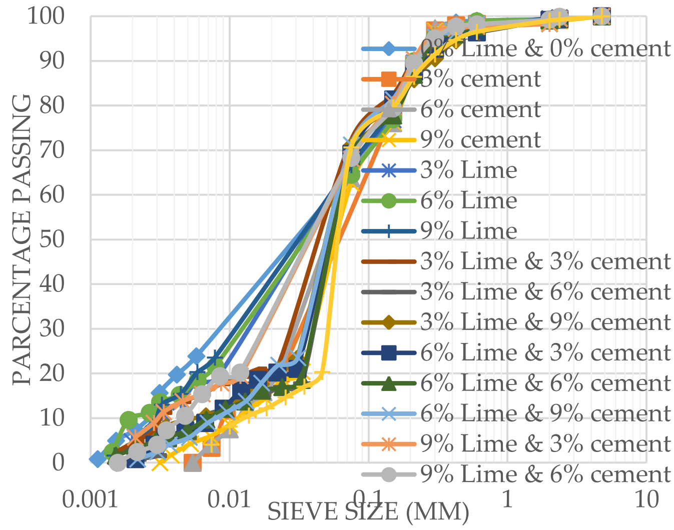

Fig. 2: Particle size distribution curve for the natural and lime/cement modified soil

3.3 Specific Gravity of Subgrade Soil Mixed with Lime and Cement

The variation of specific gravity of weak subgrade with lime/cement content is shown in Figure 3. The Specific gravity of untreated soil was found to be 2.62. The addition of admixtures in steps of 0, 3, 6 and 9% by weight of dry soil led to the decrease in Specific Gravity of untreated weak soil having the lowest value at 9 % treatment. The decrease in specific gravity is due to the lower specific gravity of lime (2.34) compared to that of the untreated soil (2.62) (Salahudeen, 2014).

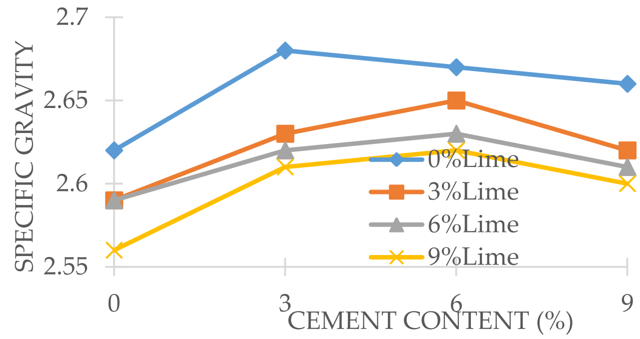

Fig. 3: Variation of specific gravity of subgrade soil with lime/cement content

3.4 Atterberg Limits of Subgrade Soil Mixed with Lime and Cement

Figures 4 - 6 show the variation of Atterberg limits (liquid limit, plastic limit and plasticity index) of subgrade soil with lime/cement content. The introduction of lime and cement into the soil caused a continuous increase in liquid and plastic limits while the plasticity index decreased. The increase can be attributed to addition of lime and cement which introduced more pozzolanic substance into the specimen that required more water for hydration to be completed (Salahudeen et al. 2014). This observed trend is in agreement with Ramzi et al. (2001), Venkaramuthyalu et al. (2012), Salahudeen and Ochepo (2015), Sadeeq et al. (2014 a, b, c) Sadeeq et al. (2015), Salahudeen and Sadeeq (2016a; b) and Sadeeq and Salahudeen (2017). Suhail *et al.* (2008) and Venkaramuthyalu *et al.* (2012) reported that the reduction in plasticity index with chemical treatment could be attributed to the depressed double layer thickness due to cation exchange by potassium, calcium and ferric ions.

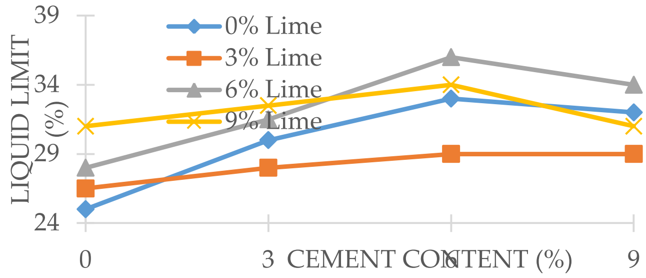

Fig. 4: Variation of liquid limit of of subgrade soil with lime/cement content

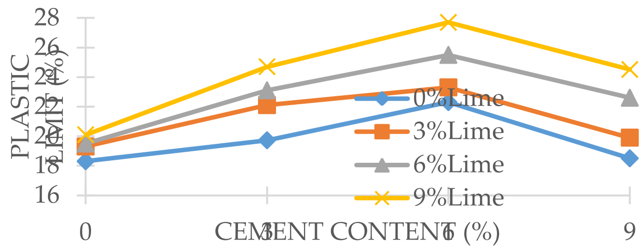

Fig. 5: Variation of plastic limit of subgrade soil with lime/cement content

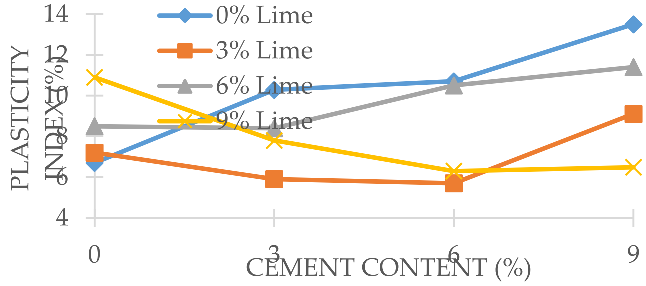

Fig. 6: Variation of plasticity index of subgrade soil with lime/cement content

3.5 Compaction Characteristics of Subgrade Soil Mixed with Lime and Cement

The variations of maximum dry density (MDD) and optimum moisture content (OMC) of the weak subgrade soil used in this study with lime/cement content are shown in Figures 7 and 8. According to Alhassan (2008) and Salahudeen (2014), the increase in the MDD can be attributed to the replacement of soil by lime and cement in the mixture. It may also be attributed to coating of the soil by the lime and cement which resulted to formation of larger particles and hence the increase in MDD. The increase in the MDD may also be explained by considering the lime/cement mix as filler in the soil voids which increased the weight of the soil/lime/cement matrix. According to Salahudeen *et al.* (2014) and Salahudeen (2014), the increase in MDD could be due to lime occupying the voids within the soil matrix as well as the flocculation and agglomeration of the clay particles due to exchange of ions. There was a continuous decrease in OMC with increased lime/cement contents. The trend is in line with Osinubi (1999) and Salahudeen (2014). The decrease may be due to the addition of lime and cement, which decreased the quantity of free silt and clay fraction and coarser materials with larger surface areas were formed. The decrease in OMC with increase in lime content might also be due to cation exchange reaction that caused the flocculation of clay particles (Salahudeen and Akiije, 2014; Salahudeen *et al.* 2014; Salahudeen, 2014, Sadeeq and Salahudeen, 2017).

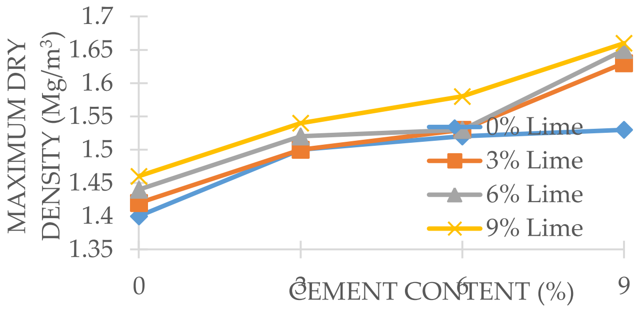

Fig. 7: Variation of maximum dry density of subgrade soil with lime/cement content

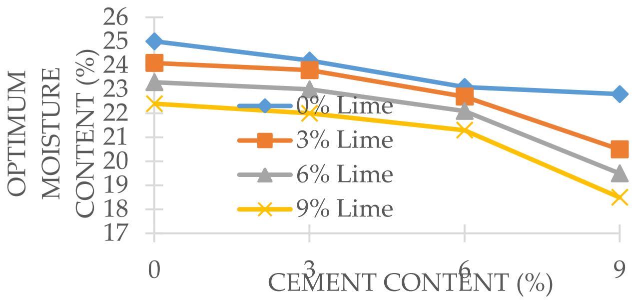

Fig. 8: Variation of optimum moisture content of subgrade soil with lime/cement content

3.6 Unconfined Compressive Strength of Subgrade Soil Mixed with Lime and Cement

The variation of unconfined compressive strength (UCS) of natural weak subgrade soil treated with cement and lime contents for 7, 14 and 28 day curing periods are shown in Figures 9 - 11. The UCS values increased with increase in both cement and lime contents having peak values at 9%Lime/9%cement contents. The peak values for the 7, 14 and 28 day curing periods are 370.42, 377.50 and 446.77 kN/m^2 respectively. The observed trends can be attributed to ion exchange at the surface of clay particles. The Ca^{2+} in cement reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration of the clay particles (Salahudeen *et al.*, 2014).

The increase in the UCS values was primarily due to the formation of various compounds (as presented in Table 2), such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro-fabric changes, which are responsible for strength development in the soil matrix. This result is in agreement with findings of Osinubi *et al.*, (2011) and Sadeeq *et al.* (2014). Although the strength of the natural weak soil improved with both cement and lime treatment, none of the values at all additive contents met the 1710 kN/m^2 unconfined compressive strength value specified by TRRL (1977) as a criterion for adequate stabilization using Ordinary Portland Cement.

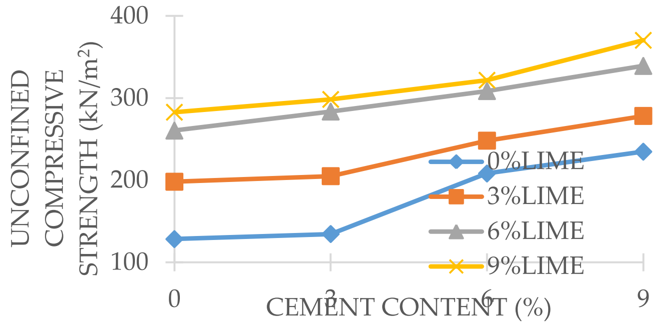

Fig. 9: Variation of 7 days curing period unconfined compressive strenght of subgrade soil with lime/cement content

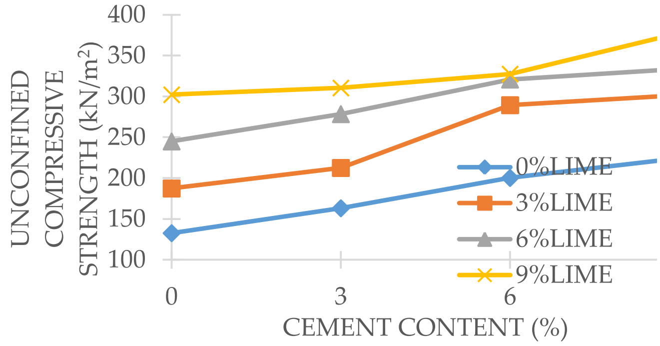

Fig 10: Variation of 14 days curing period unconfined compressive strenght of subgrade soil with lime/cement content

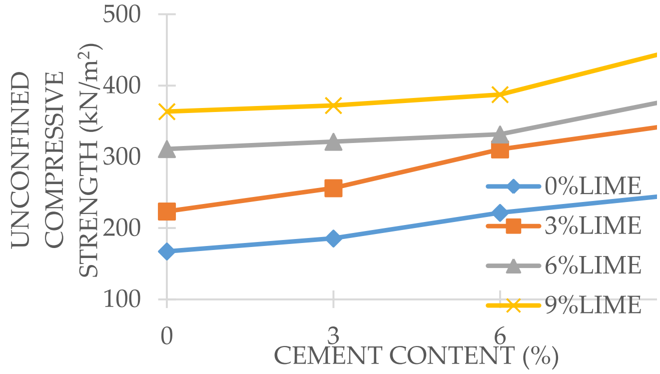

Fig. 11: Variation of 28 days curing period unconfined compressive strenght of subgrade soil with lime/cement content

3.7 California Bearing Ratio of Subgrade Soil Mixed with Lime and Cement

The variation of unsoaked and soaked (24-hour soaking) California Bearing Ratio (CBR) values of the soil with cement and lime contents are shown in Figures 12 and 13 respectively. Generally, the CBR values recorded increased with higher cement and lime contents. Peak CBR values of 80.30 and 83,90 % were obtained for the unsoaked and soaked samples at 9%Lime/6%cement contents and 9%Lime/9%cement contents respectively. These observed CBR values are suitable for subgrade and sub-base materials according to FMWH (1997), Amadi *et al.* (2015) and Gidigasu and Dogbey, (1980). This increase in CBR values could be due to the presence of adequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain in soil stabilization (Salahudeen *et al.*, 2014).

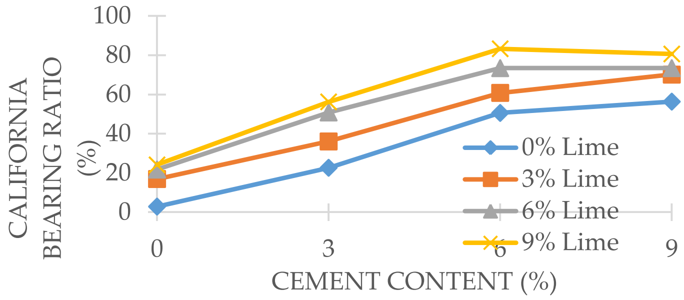

Fig. 12: Variation of unsoaked California bearing ratio of subgrade soil with lime/cement content

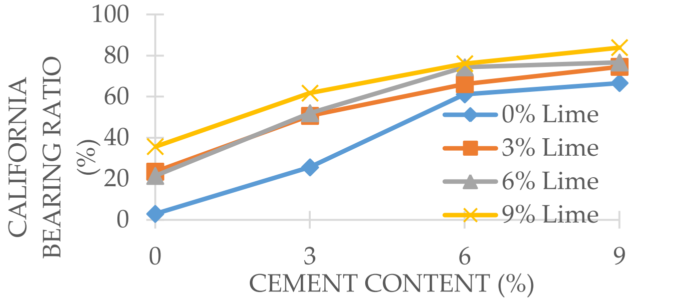

Fig. 13: Variation of soaked California bearing ratio of subgrade soil with lime/cement content

4 Conclusion

Based on the results of this study, the following conclusions were drawn:

1. The weak base soil collected in Baure L.G.A of Katsina State is classified as A–4 soil using AASHTO classification system and inorganic clay material CL using the USCS. The study results showed that cement and lime can be beneficially used to improve the engineering properties of weak subgrade soil.
2. The Atterberg limits of the weak subgrade soils improved having a minimum plasticity index value of 5.70 % at 3%Lime/6%Cement contents. This result meets the maximum values of 12 % plasticity index specified by clause 6201 of the Nigerian General Specifications (1997) for sub-base materials.
3. The maximum dry density values obtained showed a significant improvement having a peak value of 1.66 kN/m^3 at 9%Lime/9%Cement contents of admixtures. Similarly, a minimum value of 18.50 % was observed for optimum moisture content at 9%Lime/9%Cement contents of admixtures which is a desirable reduction from a value of 25.00 % for the natural soil.
4. For the strength characteristic tests, the unconfined compressive test value increased from 167.30 kN/m^2 for the natural soil to 446.77 kN/m^2 at 9%Lime/9%Cement contents 28 days curing period. Likewise, the soaked California bearing ratio values increased from 2.90 % for the natural soil to 83.90 % at 9%Lime/9%Cement contents.
5. Generally, there were improvements in the engineering properties of the weak subgrade soil when treated with lime and cement. These improvement increases with increase in the admixtures contents. However, the peak UCS value of 446.77 kN/m^2 fails to meet the recommended UCS value of 1710 KN/m^2 specified by TRRL (1977) as a criterion for adequate stabilization using Ordinary Portland Cement.

REFERENCES

Abu-Farsakh, M. A. (2004). *Assesment of in-situ test technology for construction control of base courses and embankments.* Louisiana: Louisiana Transportation Research Center First Edt.

Alhassan, M. (2008). *"Potential Of Rice Husk Ash For Soil Stabilization*". *Assumption University Journal of Technology*. Vol. 11, No. 4. pp.246-250.

Amadi A.N.1, A. W. (2015). Assessment of the Geotechnical Properties of Lateritic Soils in Minna, North Central Nigeria for Road design and Construction . *Journal of Science and Education*, 2 - 7.

American Association of State Highway and Transportation Officials (AASHTO), (1986) Washington, D. C.. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Twentieth Edition".

Anderson, J. N. (2012). Soil Cement Stabilization - Mix Design, Control and Results during Construction. *International Symposium on Ground Improvement IS-GI Brussels*, 1 - 5.

ASTM C618-93 specification (1992) "Fly Ash and Raw or Calcined Natural Pozzolan for use as Mineral Admixture in Portland Cement Concrete".

Bhattacharja, S. A. (2003). *Comparative performance of the Portland cement and lime stabilization of moderate to high plasticity soils.* Washington D.C: CD-ROM publication, National research council, Washington D.C.

British Standard (BS) 1377 (1990) "Methods of Test for Soils for Civil Engineering Purposes".

British Standard (BS) 1924 (1990). *Methods of Tests for Stabilized Soils.* British Standards Institute, London.

Nigerian General Specification (1997): Road Works and Bridges, Federal Ministry of Works and Housing, Abuja, Nigeria.

Osinubi, K. J. (1999). "Evaluation of admixture stabilization of Nigerian black cotton soil." *Nigerian Society of Engineers Technical Transactions*, Vol. 34, No 3, pp 88-96.

Ramzi, T., Amer, A., Ali, A. and Hilia A. (2001). "*Use Of Cement Kiln Dust In Soil Stabilization*". EJUQ. Vol.14 pp.61-76.

Sadeeq, J. A., Ochepo, J. and Salahudeen, A. B. (2014 a). "Effect of used oil contamination on the volumetric shrinkage of lateritic soils." Proceedings of the Third International Conference on Engineering and Technology Research, Ladoke Akintola University of Technology , Ogbomoso, Nigeria Volume 3, pp 167-175.

Sadeeq, J. A., Ochepo, J. and Salahudeen, A. B. (2014 b). "Assessment of bagasse ash effect on the volumetric shrinkage of lateritic soils for flexible pavements." Proceedings of the Nigerian Engineering Conference, Ahmadu Bello University, Zaria, Nigeria, pp 241-248.

Sadeeq, J. A., Ochepo, J. and Salahudeen, A. B. (2014 c). Effect of bagasse ash on consolidation settlement characteristics of lateritic soils. Proceedings of the national conference on "Bridging the gap between academia and industry in Nigeria-Refocosing the engineering discipline." Faculty of Engineering, Bayero University, Kano, Nigeria, pp 573 – 587.

Sadeeq, J. A., Ochepo, J., Salahudeen, A. B. and Tijjani, S. T. (2015). Effect of bagasse ash on lime stabilized lateritic soil. Jordan Journal of Civil Engineering (JJCE), Vol. 9, No.2.

Sadeeq, J. A. and Salahudeen, A. B. (2017). Strength characterization of foundation soils at Federal University Lokoja based on standard penetration tests data. *Nigerian Journal of Technology (NIJOTECH),* Vol. 36 No. 3, Pp. 671 – 676.

Salahudeen, A.B., Akiije, I. and Usman, G.M. (2013). Effect of sectional modulus on universal and hollow steel columns subjected to flexure. IJERT. Vol. 2 issue 9, pp 1848-1864.

Salahudeen, A. B. (2014). Stabilization of black cotton soil with cement kiln dust. Unpublished M.Sc. thesis, *Department of Civil Engineering,* Ahmadu Bello University, Zaria.

Salahudeen, A. B. and Akiije, I. (2014). Stabilization of highway expansive soils with high loss on ignition content kiln dust. *Nigerian journal of technology (NIJOTECH),* Vol. 33. No. 2, pp. 141 – 148.

Salahudeen, A. B., Eberemu O. A. and Osinubi, K. J. (2014). Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements. Geotechnical and Geological Engineering, Springer, Vol. 32, No. 4, PP. 923-931.

Salahudeen, A. B. and Ochepo, J. (2015). Effect of bagasse ash on some engineering properties of lateritic soil. Jordan Journal of Civil Engineering (JJCE), Vol. 9, No.4.

Salahudeen, A. B. and Sadeeq, J. A. (2016a). Effect of rice husk ash on the index properties and hydraulic conductivity of lateritic soils for flexible pavement construction. *Proceedings of NIMACON 2016, Material Science and Technology Society of Nigeria (MSN),* Ahmadu Bello University, Zaria, pp. 1 – 6.

Salahudeen, A. B. and Sadeeq, J. A. (2016b). Strength characteristics of lateritic soils treated with rice husk ash for earth road construction. *Proceedings of NIMACON 2016, Material Science and Technology Society of Nigeria (MSN),* Ahmadu Bello University, Zaria, pp. 7 – 11.

Shriram M., A. K. (2015). Stabilization of Lateritic Soil Subgrade Using Cement, Coconut Coir and Aggregates. *International Journal of Innovative Research in Science, Engineering and Technology*, 2 - 6.

Suhail, A.A.A., Khawla, A.K.A. and Ibrahaim, M.A.A. (2008). "*Strength Durability And Hydraulic Properties Of Clayey Soil Stabilized With Lime And Industrial Waste Lime*". Al-Rafidain Engineering. Vol. 16. No. 1. Pp.102-116.

TRRL (1977). "A guide to the structural design of bitumen surfaced roads in tropical and sub-tropical countries." *Transport and Road Research Laboratory, Road Note 31*, H. M. S. O., London.

Venkaramuthyalu, P., Ramu, K., and Prasada, R.G.V.R. (2012). "*Study on performance of chemically stabilized expansive soil*". IJAET, Vol. 2, Issue 1, pp 139-148.